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BIRD FLIGHT.

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B I R D F L I G H T.*

(Hints to be Obtained from it for Use in Aviation.)

By Dr. Magnan, D. Sc.

The flight of birds has long interested minds desiring to understand nature, but it is especially in our own day that more thorough investigations have been undertaken, with a view to discovering the laws of aerial locomotion peculiar to certain groups of animals. In France, as in other countries, men have devoted themselves with enthusiasm to the study of the organs of flight of birds in particular and many have already published the results of their researches, some on the wing surfaces and some, more rare, on other parts of the organism of birds utilized during flight, such as the tail and the muscles of the wing.

Among the former, we recall the names of Dubochet (1834), Prechtl, (1846), De Lucy (1865), Hartings (1869), Mouillard (1880), Marey (1884), Mullenkoff (1884) and Richet (1909). Among the latter I will mention Legal and Reichel, who studied comparative anatomy, in order to determine the relative weight of the different wing muscles.

Although the various authors give us interesting information, we should not be obliged to make an exhaustive study of all these different sources, as Marey very aptly remarked in 1890. This great scientist thought that experimental investigations would be greatly facilitated by a compilation of the scattered data. In fact, the various interpretations had not, up to that time, enabled the deduction of general laws. There were many facts which had not then been observed, but which could not however be disregarded.

It was just because no collective study had been made of the characteristics of birds and their relation to the kind of flight, that I was led quite naturally, more than ten years ago, to devote myself to the problem of the adaptation of the organs of birds to their aerial life, as a result of the researches I had already made on the influence of the surrounding medium on the internal and external morphology of vertebrates.

Convinced that the plastic body of the bird, with its "fuselage" and supporting surfaces, can only be the result of the moulding action of the air, which offers considerable head resistance, I tackled the problem with an unusual breadth of view and extended my researches to more than 500 birds, from large species, like the rhea, lammergeier, albatros and great bustard, to very small birds, such as wrens. I have thus collected 17,000 numerical data, which have given me nearly 30,000 ratios. Though, in

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this respect, I have done work of a biological nature, like many of my predecessors, I have, on the other hand, been the first to demonstrate that the conclusions obtained from studying the characteristics of birds can lead to practical applications in aviation and that they can suggest many ideas for the construction of airplanes and the determination of their shape.

While measuring and dissecting birds, I carefully observed the manner of flight of the various species I was studying. This is evidently an essential condition for the successful study of the adaptation of birds to all the conditions of aerial life. For this purpose, I have traversed plains, visited woods, skirted the sea shore, and made ocean voyages. I have even gone to Tunis and Tripoli, in the endeavor to ascertain the manner of flight of each species. I cannot give the details of these observations here, but will, however, state the conclusions I have drawn from them.

I soon found that birds employ many kinds of flight, but I consider it reasonable, if we would not complicate the problem, to reduce these kinds to two types, flapping and soaring, remembering that, while we have in nature all degrees of transition from one to the other, one of them predominates for each kind of bird.

Flapping flight consists in successive blows of the wings, this method being employed more or less, according to the species. All the carinatae are capable of flapping their wings and can support themselves in the air by this means. It has long been known that nearly all birds, before rising, endeavor to acquire a preliminary speed by running on the ground with their heads to the wind, like the vulture, the stork and the bustard, or on the water, like the albatros, or by dropping from an elevated place, like the goshawk and the martins, or by jumping to a sufficient height in comparison with their size, like the small waders, the gallinae and sparrows. At this instant, all species flap more or less violently, in order to acquire altitude.

A large number of species belonging to all the groups, from the raptores to the palmipides, employ flapping flight exclusively. For many, this manner of flight is habitual and is practically continuous. Some birds, after attaining sufficient altitude, cease flapping and glide through the air. Most swallows fly thus. They have a peculiar kind of flight, consisting of alternate periods of rapid flapping and complete cessation of flapping. When the speed acquired seems sufficient to the bird, he closes his wings and shoots through the air like an arrow.

Other birds, like the gallinae and martins, after a series of strong rapid strokes, hold their wings rigidly extended and glide for a short space of time. There are other birds capable

of gliding for a comparatively long period of time. Such are all the species provided with large wings, like birds of prey, large waders and long-winged, web-footed birds. They flap their wings much less frequently than the members of the other groups. Their wing strokes are always made slowly and but few in succession. Generally, as soon as they have attained a more or less elevated position, according to the species, they glide with their wings outspread at right angles to their bodies. Thus they describe successive circles, each a little lower than the last. This gliding flight is executed even in still air.

We see from the above statements that all birds flap more or less and glide more or less and that it is not necessary to separate the two kinds of flight. They are, in fact, only two different phases of the same manner of aerial locomotion, one phase being utilized more than the other by the bird during the course of its flight, according to the different conformations of the various species, as clearly demonstrated by my investigations.

Gliding flight, of whatever length, during which the bird loses altitude, must not be confounded with soaring flight. The latter may be continuous, but requires for its production, at least according to my personal observations, the existence of a more or less strong wind and its action against the under side of the wings.

I hold the opinion that there are two kinds of soaring flight. In one kind the bird utilizes ascending currents, the wind having been forced to ascend by encountering a mountain, for example, or as a result of the air becoming heated near the ground. Birds of prey often practice soaring flight, like the eagle in the mountains and the vulture over the desert. With their wings wide open, they can thus rise in the air till lost to view, generally in a spiral motion, without flapping their wings. In the other case, the bird mounts on the wind (which may be horizontal) while facing it. With his wings more or less extended, according to the strength of the wind, he does not give a single stroke, but merely balances, in order to maintain his equilibrium. By means of this wind he acquires altitude, his ascent always being quite slow. In order to hold any desired direction, he uses his tail as a rudder. He also uses it as an elevator, if the wind has a tendency to upset him. When the bird, which never flies at a great altitude under these conditions, ceases to face the wind (after a turn, for example), he makes a swift glide with the wind behind him and wings outspread, thereby losing in altitude. In soaring flight, there are accordingly two phases. The first corresponds to the first phase of flapping flight with the difference that a soaring bird, in contradistinction to a flapping bird, makes no effort to raise himself and finds the force required for his elevation not in the muscles of his body, but in the surrounding medium. The second phase, on

the contrary, is the same in both methods of flight, since both the soaring and the flapping bird utilize and combine two forces, the force of gravity and the resistance offered by the air to their fall, according to the area of their supporting surfaces, for the purpose of controlling the speed of their descent.

Good soaring birds, which fly against the wind, can maintain themselves in the air for a long time without giving a single stroke with their wings. It has seemed to me that birds made their best flights when the wind appeared to an observer on the ground to be continuous, but reinforced at intervals by squalls. This kind of soaring flight can be employed only by certain species having a special conformation, of which I will speak farther on. Among birds of this type are the albatros, frigate bird, gannet, petrels and gulls. For soaring flight, the three former species do not require a strong wind. The two latter families, on the contrary, seldom practice soaring flight without a strong wind.

The flapping bird also utilizes the wind. He can also make soaring flights in the theoretical sense of the term, but since his conformation does not enable him to be a true soarer, he only utilizes the wind to diminish his efforts in flapping. Thus the small waders and quails, which possess characteristics recalling in miniature those of the gannets and gulls, succeed in flying across long stretches of sea in their migrations, for which their own motive power would be insufficient.

This introduction was necessary, in order to call attention to the differences in the organs of flight of the different classes of birds. These differences I will now proceed to explain.

As a result of my investigations of the various methods of flight employed by birds, I have been led to classify them in thirteen groups.

I. - Raptores, day, soarers, which seldom flap their wings and, for the most part, practice soaring flight with ascending wind: vultures, lammergeiers, eagles, buzzards, hawks and ospreys.

II. - Raptores, day, flapper-gliders, capable of making quite long glides, but which ascend or fly horizontally only by more or less rapid strokes of their wings: falcons, goshawks and sparrow hawks.

III. - Raptores, night, flapper-gliders, which only flap their wings very slowly and can glide in a remarkable fashion: owls.

IV. - Palmipedes, soarers, which, without effort, fly against the wind for hours at a time, with only an occasional stroke of their wings: albatros, frigate-bird, gannet, petrels and gulls.

V.- Corvidae, flapper-gliders: crows, blackbirds, magpies.

VI.- Grallae, flapper-gliders: herons, storks, cranes, bitterns.

VII.- Passeres, flapper-gliders: night-hawks, martins, swallows Quite long glides, frequently interrupted by flapping flight.

VIII.- Passeres, flappers: most small birds which flap rapidly, shoot ahead, like an arrow, with their wings partially closed and then resume flapping.

IX.- Grallae, flappers: bustards, sand-pipers, plovers, lapwings.

X.- Columbae, flappers: pigeons.

XI.- Gallinae, flappers: grouse, partridges.

XII.- Palmipedes, swimmer-flappers: geese and ducks, which flap rapidly, never glide and only hold their wings extended in alighting.

XIII.- Palmipedes, diver-flappers: which seldom fly and which must be separated from the swimmers for this reason and also on account of their adaptation to life in the water.

With the aid of the above classification, it is possible to explain the differences discovered in birds, when studying the characteristics of their organs of flight. Of the latter, the wings appear, at first thought, to be the most important. Hence the study of the wing areas has given rise to numerous treatises. The ratio of the area of the wing to the weight of the body has for a long time drawn the attention of scientists interested in bird flight.

Dubochet was the first to show that, among birds of the same shape and manner of flight, but of different sizes, the smallest has the largest relative wing surface.

Mouillard, by like comparisons, arrived at the following conclusion:

"The relative surface area required by a bird for a given kind of flight diminishes with the increase in weight of the bird."

Some scientists even now assume that the various species of birds are provided with wing areas, which vary inversely as the weights of their bodies and this fact seems to constitute for many writers one of the most important and difficult problems to solve. It has even been thought that its solution would be one of the most useful discoveries for aerial navigation.

In taking up the study of the wing area of birds, instead of calculating the area geometrically like most of my predecessors, I obtained it as accurately as possible by spreading the wings on paper ruled in square millimeters. I then drew their outlines, including the digitated spaces frequently occurring at the end of certain wings. I was thus able to obtain quite accurately the actual area of the wings in square centimeters.

I first divided these actual areas, expressed in square centimeters, by the weight of the body, expressed in grams. I then found the wing area per kilogram of the weight of the bird. The following are the mean results for the various classes of birds.

	Av. wt. of body		Wing Area	
	kg.	pounds	in sq. dm. per kg. of bird	in. sq. in. per lb. of bird
Grallae, flapper-gliders	2.61411	5.763	20.3	142.72
Palmipides, soarers	1.6084	3.546	21.3	149.75
Raptores, day, soarers	1.4027	3.092	34.4	241.85
Palmipides, swimmer-flappers	.9666	2.131	9.2	64.68
Palmipides, diver-flappers	.8368	1.845	7.4	52.03
Gallinae, flappers	.6990	1.541	10.4	73.10
Raptores, night, flapper-gliders	.5307	1.170	40.8	286.85
Raptores, day, flapper-gliders	.4137	0.912	27.5	193.33
Columbae, flappers	.3263	0.719	17.9	125.83
Corvidae, flapper-gliders	.3256	0.718	28.6	201.07
Grallae, flappers	.2469	0.544	22.7	159.60
Passeres, flapper-gliders	.0350	0.077	62.6	440.11
Passeres, flappers	.0347	0.0765	52.1	366.30

From the above table it may seem to follow that there is an inverse ratio between the wing area per kilogram and the weight of the body. It would also appear that this ratio does not vary in a simple manner. At the most, it may be said in a general way that large birds have smaller wings in proportion to their weight than small birds. This statement is, moreover, contrary to current observation. In fact, if we consider a quail and a screech-owl, it is evident that the latter has the larger wings, though the ratio just referred to would give the contrary result. We may say therefore that this result has no significance, but that it is the consequence of mathematical expedients. In fact, the ratio

$$\frac{\text{Wing area}}{\text{Weight of body}} - \frac{Kl^2}{K'l^3} = \frac{K}{K'l}$$

is not homogeneous. It is a function of a linear dimension of the bird. Hence the larger this linear dimension, the smaller the ratio in question.

The simple study of this ratio would present little of interest, if it did not render it possible to show that, in spite of the mathematical expedient, it is possible to explain in part the real differences in wing surface in the different types. For this purpose, it suffices to compare, in the above table, the groups of mean weights which are the nearest alike. Thus the palmipides swimmer-flappers (geese and ducks) have four times less wing area per kilogram than the soaring day raptores (vultures and eagles), although weighing, on the average, nearly twice as little. The same is true of the day flapper-glider raptores (goshawks and falcons) and the flapper columbae (pigeons). Note that the latter which, if the law of inversion were correct, should possess the largest wing area per kilogram, have, on the contrary, the least. Consequently we can affirm that, in spite of the mathematical expedient employed, the flapper-glider day raptores have much more wing area than the swimmer-flapper palmipedes and flapper columbae. I have demonstrated this by another method. I considered it necessary to compare one area with another and thus obtain homogeneous ratios, as had previously been done by Pretchtl and others who compared the square root of the wing area with the cube root of the weight. I preferred to compare the actual wing area of the birds, expressed in square centimeters, with the surface of the body calculated by the formula

$$\sqrt[3]{P^2}$$

P being expressed in grams. Under these conditions, we obtain ratios of the relative surface areas, which are more readily compared, are homogeneous, and have an indisputable value. Moreover, we shall see farther along that this method makes it possible to determine the ideal dimensions of airplanes capable of sustaining themselves in the air by soaring or gliding like birds.

Here are the average results which I found for the different classes of birds:

	Av. wt. of body		Ratio of wing area	Weight of wings	
	in kg.	in pounds	to area of body	in grams per kg. of bird	in ounces per lb. of bird
Raptores, day, soarers	1.4027	3.092	26.7	227.8	3.64
Raptores, night, flapper-gliders	0.5307	1.170	25.2	195.4	3.13
Grallae, flapper-gliders	2.6141	5.763	23.8	186.5	2.98
Palmipides, soarers	1.6084	3.546	21.3	189.0	3.02
Passeres, flapper-gliders	0.0350	0.077	19.0	152.2	2.44
Corvidae, flapper-"	0.3256	0.718	19.0	143.7	2.30
Raptores, day, flapper-gliders	0.4137	0.912	18.1	180.8	2.89
Passeres, flappers	0.0347	0.0765	14.3	108.5	1.67
Grallae, flappers	0.2469	0.544	12.4	113.1	1.81
Columbae, flappers	0.3263	0.719	11.9	141.2	2.26
Palmipedes, swimmer-flappers	0.9666	2.131	8.5	105.8	1.69
Gallinae, flappers	0.6990	1.541	8.1	91.7	1.47
Palmipedes, diver-flappers	0.8368	1.845	6.4	81.5	1.30

We see that the ratio of the wing area to the surface area of the body varies greatly for the different types, the extremes being 6.4 and 26.7. The average figures may vary with the number of birds examined. They are correct for the weights given. In any event, they would be very near those contained in the table, even if the weights were different.

I wished to find also the actual surface area of the body of the bird in square centimeters. For this purpose, I adopted a novel method. I made a heavy paint by mixing 26 grams of white lead with 100 g. of linseed oil. I covered the body of the bird with this paint. It sufficed to weight the picked body before and after painting, in order to find the exact weight P of the paint applied. By weighing beforehand a piece of skin (one decimeter square, for example) and covering it with the same paint, I found a weight p representing the quantity of paint required to cover a square decimeter of skin. All that was now necessary was to divide the weight P by the weight p to obtain the exact area of the body S in sq. cm. On dividing the actual area of the wings by S, I obtained ratios identical with those of the foregoing table.

According to all the evidence, therefore, birds are unequally equipped with supporting surface. Those which have the largest relative supporting surface are soarers or good gliders. In fact, they are able to make soaring or gliding flights of long duration, just

because they are so well equipped. A good glider behaves like an airplane provided with large wings which, with the engine stopped descends slowly, with the inclination of its trajectory dependent on its qualities and wing section.

Large soaring birds, like the palmipedes which utilize horizontal flight, have a smaller wing area than the soaring raptores, which utilize ascending air currents and consequently require a larger wing area for more efficacious action.

On the contrary, the groups with a small relative wing area are all continuous flappers. Some, like the gallinae, can make short glides, when their speed is great enough. They find themselves, therefore, under the same conditions, at the moment of alighting, as certain small swift airplanes like the one used by Sadi Lecointe. Others, like the flapper passeres, i.e. most small birds, do not glide at all. As soon as they have acquired a high speed by a series of rapid strokes, they fold their wings against their body, but their supporting surface does not become absolutely zero. It is simply ten times as small as in flapping flight and only serves to balance the body in its forward motion, until its speed has so far decreased that the bird must resume flapping, in order to avoid falling. For a brief period, the bird passes through the air like a projectile and describes, like the latter, a sort of ballistic curve. In short, below a relative wing area of 16, true gliding becomes impossible and continuous flapping flight is alone possible, this being so much the shorter and more defective, as the wing area is more reduced. For this reason, the gallinae and diving palmipedes fly but little and spend most of their time on the ground or in the water.

It is possible to show in a still more striking manner the differences in the wing areas of the various classes of birds. For this purpose, I took photographs of wings and reduced them to the dimensions they would have if each bird weighed only one gram. Figure 1 shows the variations in wing area. This method, which is strictly accurate, facilitates the comprehension of the differences which would appear even without this expedient. It shows the relative wing area for each type. It is obvious that this mechanical process gives the same classification as obtained by taking the mean ratio of the wing area to the area of the body, in the various groups.

I have also found the weights of the wings of all the birds I have studied and determined the ratios of these weights to the weights of the bodies. The mean values obtained are given in the foregoing table. The classification, which gives the relative weight of the wings, reproduces, on the whole, the one furnished by the relative surface of the wings, which proves that my method of analysis is a good one. Anyway, it may be noted that certain wings appear more or less light or heavy. A detailed examination

of the figures shows, in fact, that for the same wing area, the soarers have very heavy wings, as also certain flappers, like the columbae, or certain flapper-gliders, like goshawks. On the contrary, other groups, such as the grallae and flapper passeres, have very light wings.

Nevertheless, there is one characteristic, designated in aviation by the name of "load," which represents the number of kilograms lifted per square meter of lifting surface, which our statistics do not show.

The load, the ratio of weight to area, is not a number. It conserves a linear dimension of the airplane or bird considered and can consequently serve for legitimate comparisons only between airplanes or birds of like size.

As regards airplanes, when they are of nearly the same weight this comparison is an interesting one to make. But if it is a question of comparing, without precautions, the load of an airplane with that of a bird ten times as small, or that of an eagle with that of a humming-bird, we run the risk of committing very great errors and, for example, of being led to conclude, as has already happened, that the largest birds are the most poorly equipped for flight, which is manifestly incorrect.

Nevertheless, for comparison with airpl anes, it would perhaps be useful to determine the value of the loads. In each class I have found the average total weight and the average load supported per square meter. These are given in the first two columns of the following table.

	Av. wt. of body in kg.	Load P/S in kg.	Load P/S in lbs.	K	$\sqrt[3]{K}$	$\sqrt[3]{K\frac{P}{S}}$ in kg.	$\sqrt[3]{K\frac{P}{S}}$ in lbs.
Grallae, flapper-gliders	2.6141	5.5	12.13	1.0	1.00	5.5	12.13
Palmipedes, soarers	1.6084	7.0	15.43	1.6	1.17	8.1	17.86
Raptores, day, soarers	1.4027	3.7	8.16	1.8	1.21	4.4	9.70
Palmipedes, swimmer-flappers	.9666	11.1	24.47	2.7	1.39	15.4	33.95
Palmipedes, diver-flappers	.8368	15.0	33.07	3.1	1.45	21.7	47.84
Gallinae, flappers	.6990	10.6	23.37	3.7	1.54	16.3	35.94
Raptores, night, flapper-gliders	.5307	2.8	6.17	4.9	1.69	4.7	10.36
Raptores, day, flapper-gliders	.4137	3.9	8.60	6.3	1.84	7.1	15.65
Columbae, flappers	.3263	5.6	12.35	8.0	2.00	11.2	24.69
Corvidae, flapper-gliders	.3256	3.5	7.72	8.0	2.00	7.0	15.43
Grallae, flappers	.2469	4.8	10.58	10.5	2.18	10.4	22.93
Passeres, flapper-gliders	.0350	1.5	3.31	74.6	4.20	6.3	13.89
Passeres, flappers	.0347	2.5	5.51	75.3	4.22	10.7	23.59

The birds being arranged in decreasing average weights, it would be quite natural, after what we have explained, to expect also an arrangement by decreasing loads. Now, this decrease of load is not manifest. There is therefore one phenomenon, which the arithmetical expedient mentioned does not cover.

As I have already said, the comparison of the loads is legitimate for birds of like size. Now, supposing that all birds have the same density, which is sufficiently accurate, and the same or similar shape (which is not sufficiently accurate) and letting

$$p_1, p_2, p_3 \ldots p_n$$

represent the different average weights, the expressions

$$\frac{p_1}{p_1} = K_1, \frac{p_1}{p_2} = K_2, \frac{p_1}{p_3} = K_3 \ldots \frac{p_1}{p_n} = K_n$$

give us such values for K that, if, for example, we multiply the weight $p\alpha$ by $K\alpha$, we will obtain p_1.

In the same manner, with the given hypotheses, if we multiply an area $S\alpha$ by the coefficient $\sqrt[3]{K\alpha^2}$, we will obtain S_1, the same surface in the first group of birds.

In the same way again, if we multiply a length $L\alpha$ by the coefficient $\sqrt[3]{K\alpha}$, we will find L_1, the same dimension in the first group of birds.

Such being the case, the load P/S is a certain number N multiplied by a linear dimension L, so that in a general way, if the birds were similar and if the law of Hartings were correct, we would have

$$\frac{p_1}{S_1} = \frac{K\alpha\ p\alpha}{K\alpha^{\frac{2}{3}}\ S\alpha} = \sqrt[3]{K\alpha}\ \frac{p\alpha}{S\alpha}$$

I then calculated the coefficients K and $\sqrt[3]{K\alpha}$, multiplied each load by the corresponding coefficient and found, lastly, the numbers in the last column of the foregoing table, which give the loads supported by the wings of the different orders of birds, reduced to the same size of body, i.e. to about the size of a bird with a span of one meter.

The loads are necessarily unequal. Their consideration enables the following classification.

Groups.	Load in kg/m²	Load in lbs/ft²
Raptores, day, soarers	4.4	0.90
Raptores, night, flapper-gliders	4.7	0.96
Grallae, flapper-gliders	5.5	1.13
Passeres, "	6.3	1.29
Corvidae, "	7.0	1.43
Raptores, day, "	7.1	1.45
Palmipides, soarers	8.1	1.66
Grallae, flappers	10.4	2.13
Passeres, "	10.7	2.19
Columbae, "	11.2	2.29
Palmipides, swimmer-flappers	15.4	3.15
Gallinae, flappers	16.3	3.34
Palmipides, diver-flappers	21.7	4.44

It is interesting to note that, if the present airplanes were similarly reduced to the same size as the above, i.e. to the size of a bird with a span of one meter, certain groups of birds would be found to carry a considerably heavier load. Thus an airplane of ten meters span, carrying 40 kg. per square meter, reduced to a span of one meter, would not carry more than 4 kg. per square meter. A palmiped diver-flapper of ten meters span would support 217 kg. per square meter.

It is, moreover, possible to compare birds with airplanes more accurately and to determine the various loads by the method I have employed for birds alone. For this purpose I calculated the loads, the coefficients K and then $\sqrt[3]{K}$ for certain monoplanes, exhibited at the last aeronautic show, and for certain birds having a characteristic method of flight. I then multiplied each real load by $\sqrt[3]{K}$ and obtained the loads supported by the various airplanes and birds, reduced to approximately the same size. These numbers are given in the following table.

	Weight in kg.	Weight in lbs.	Load P/S in kg.	Load P/S in lbs.	K	$\sqrt[3]{K}$	Load $\sqrt[3]{K\frac{P}{S}}$ kg.	Load $\sqrt[3]{K\frac{P}{S}}$ lbs.
Ernoul Monoplane	2990.000	6591.81	46.0	101.41	1	1.0	46.0	101.41
Hanriot " (racer)	750.000	1653.47	106.0	233.69	4	1.5	159.0	350.53
Albatros (Palmipedes, soarer)	8.502	18.74	13.6	29.98	351	7.0	95.2	209.88
Lammergeier (Raptores, soarer)	5.385	11.87	7.2	15.87	557	8.2	59.0	130.07
Grouse (Gallinae, flapper)	1.890	4.17	17.4	38.36	1582	11.6	201.8	444.89
Guillemot (Palmipedes flapper)	1.010	2.23	23.4	51.59	2960	14.3	334.6	737.67

We find that the lammergeier, which often utilizes an ascending wind for soaring flight, and the albatros, which flies against the wind in a remarkable manner for hours at a time with scarcely a stroke of its wings, carry much more per square meter than the first monoplane, though less than the racer. The grouse, which at certain moments of its flight may be compared to the Hanriot monoplane, while gliding just before alighting, for instance, supports a greater load than the latter airplane. The guillemot, a diver capable of short flights due to the rapidity of its wing strokes, is the most powerful. Having very small wings for the size of its body, I consider it as supporting the largest load of any bird, its P/S being 23.4 kg, while the average for the species of its group is only 15 kg.

All the birds I have examined only represent empty airplanes, while I have considered the total weight of the monoplanes in flying order. A bird can, in fact, lift much more than its own weight and its supporting power is much greater than indicated in the foregoing table.

One dimension of birds, the length, seems to me worthy of careful study, since it corresponds to the length of the fuselage of an airplane. It does not, however, appear to have interested biologists at all. I measured this length in centimeters from the end of the beak to the tip of the tail, by placing the bird in the flying position with its neck extended. I divided this dimension (which, by itself, is of no value, due to the extreme variations in size of the bodies of birds) by the cube root of the weight, P being expressed in grams, in order to obtain homogeneous and comparable ratios. I found that, proportionally, the lengths of the body do not vary greatly among birds and that they are closely related to the length of the neck and tail. In the group in which the latter organs are both short, the body of the bird is shortest. It is from one to two fifths longer, when one or the other of these organs is abnormally elongated. Such is the case, for example, with the grallae flapper-gliders, like the herons, which have long necks, or the passeres flapper-gliders, like the swifts, which have long tails. This is shown very clearly in the following table, in which I have also given the relative span in the different groups.

	Mean weight in grams	Ratio of span to cube root of weight	Ratio of span to length of body	Relative length of body
Raptores, day, soarers	1402.7	14.9	2.38	6.1
Palmipides "	1608.4	14.9	2.33	6.4
Raptores, night, flapper-gliders	530.7	13.8	2.59	5.2
Grallae, flapper-gliders	2614.1	13.5	1.83	7.3
Passeres "	35.0	12.9	1.97	6.5
Raptores, day, "	413.1	12.0	2.10	5.6
Corvidae "	325.6	11.3	1.79	6.3
Grallae, flappers	246.9	10.2	1.84	5.6
Passeres "	34.7	9.5	1.61	5.9
Columbae "	326.3	9.5	1.80	5.2
Palmipides, swimmer-flappers	966.6	9.1	1.65	5.4
" diver-flappers	836.8	8.2	1.57	5.1
Gallinae, flappers	699.0	7.6	1.58	4.8

The length and width of the wings have received very little attention. The span alone has been considered by a few writers.

On examining the classification given by the span measured in centimeters and divided by the cube root of the weight, we find it to be nearly identical with the classification furnished by the wing surface divided by the cube root of the weight raised to the second power. The differences revealed by the figures are still more striking, if the types are reduced to the size of a bird weighing one gram, as I have done in Figures 2 and 3. The species represented were all photographed in the same position at the instant when the action of the air under the wings was practically zero, while the wings were being raised.

Certain groups, like the soaring palmipides, are distinguished more by the span than by the area of their wings, i.e. by long narrow wings. I will discuss this point farther on.

There is, however, one objection that may be made to these results, namely, that the dimensions of a bird are compared with the cube root of the weight of its body, because this weight varies in a given individual. For instance, a bird weighs more before, than after a migration. In order to overcome this objection, I compared the span with the length of the body of each specimen, it being evident that these two dimensions are intimately associated with each other. The mean figures obtained by this method are classified in the same manner, but there appear here several discrepancies, due to differences already mentioned in the length of the body.

The observations I have been able to make regarding the width of the wings are no less interesting. In order to have figures for comparison, I measured the width of the wings at the point of articulation of the "hand" and then compared it to the length of the body and to the cube root of the weight. I also endeavored to ascertain the acuity of the wings by dividing their span by their width. The mean figures obtained are given in the following table.

Series A.	Mean weight in grams	Ratio of width of wing to cube root of weight	Ratio of width of wing to length of body	Acuity. Ratio of span to width of wing.
Raptores, day, soarers	1402.7	0.39	2.52	5.9
Raptores, night, flapper-gliders	530.7	0.46	2.49	5.5
Corvidae, flapper-gliders	325.6	0.37	2.43	4.6
Passeres, flappers	34.7	0.36	2.17	4.4
Raptores, day, flapper gliders	413.1	0.35	2.06	5.8
Columbae, flappers	326.3	0.33	1.75	5.4
Gallinae, "	699.0	0.30	1.50	5.0
Passeres, flapper-gliders	35.0	0.29	1.95	6.7
Series B.				
Grallae, flapper-gliders	2614.1	0.30	2.25	5.9
Grallae, flappers	246.9	0.27	1.55	6.5
Palmipedes, soarers	1608.4	0.26	1.65	9.2
" swimmer-flappers	966.6	0.19	1.24	7.3
" diver-flappers	836.8	0.19	1.03	7.8

We find that, as regards the width and acuity of their wings, birds fall into two series.

1. Series A, in which the wings are wide and the acuity small. This series consists of land birds (flapper-gliders, flappers, or soarers) which utilize ascending winds.

2. Series B, composed of aquatic birds, accustomed to living in regions of strong winds and to utilizing horizontal winds as an aid to flight and even for soaring. In this series, the individuals have narrow wings of great acuity, whatever the manner of flight. Under these conditions, it would seem that the action of the air currents is the cause of this narrowing of the wings, or rather that narrow wings are necessary for flying in such a medium. As regards the passeres flapper-gliders, another reason must

be sought to explain their conformation, which is similar to that of the marine soarers.

Each group of birds is therefore distinguished by certain dimensions and a particular form of wing. Hitherto we have been contented to designate the different shapes of bird wings by the terms obtuse, sub-obtuse, acute, super-acute, sub-acute. There have, however, been only very slight and rare attempts to interpret and classify these morphological terms.

Figures 4V and 5 show the various wing shapes I have encountered. They are reduced to the dimensions they would have on birds weighing one gram and show their relative sizes.

I consider the typical shape as oval or elliptical. The wings of the day-soaring raptores are divided at their tips, as a result of the sudden narrowing of the long feathers. This fringed appearance seems to be caused by the action of the air during strokes and by the tubes of flow while soaring on an ascending wind. Similarly fringed wings are possessed in fact by other groups like the large-winged grallae, which (especially the flappers and gliders) sometimes practice soaring flight, and the night flapper-glider raptores, which fly by slow flapping or by silent gliding.

Other birds, which occasionally flutter along the rocks like butterflies, such as the tichodrome, or which fly hardly at all, like the troglodytes, have almost round wings. On the other hand, birds which always flap their wings quite rapidly, have more or less thin wings, according to the rapidity of their strokes, the wings assuming on this account, a more or less pointed shape. On most of the passeres, columbae and gallinae, it is the part called the tip, i.e. the portion of the wing beyond the wrist, which alone tapers. The wing then assumes an oval shape, with the broad end next the body. On the gallinae, moreover, the long feathers separate at their tips, as on the soaring raptores.

On the flapper-glider day raptores, which flap their wings in flying and make but little use of the wind for supporting themselves in the air, the wings become more pointed as the strokes become more rapid. All the transitions from the pointed wing are found only in the region of the tip, even to the sickle-shaped wings of the hobby-hawks (falco subbuteo) which flap rapidly, after the manner of swallows and swifts. The latter, passeres flapper-gliders, have very tapering wings, as much more pointed as their motions are more rapid.

The influence of the rapidity of the strokes on the shape of the wings is so great that the humming birds, which flap so rapidly their wings seem to vibrate, all have wings resembling sickles.

The tapered form also occurs in other groups of birds, all palmipedes in general and most of the small grallae, but the cause of the tapering in the latter case is quite different. It resides in the action of the air currents in which these species fly, the effect of which is to diminish the wing chord to such a point that certain soarers, like the albatros, are supported by surfaces comparable to narrow wands. All aquatic birds, which fly under these conditions, have narrow pointed wings, whether their method of flight is by flapping or soaring. These conditions of aerial life are probably the cause of this transformation, since the flapping grallae, like the lapwing, woodcock and bustards are provided with very large wings, only the tips of which taper like the wings of other flapping birds.

Experiments with which I am now engaged have already convinced me that the explanations just given of the causes of the variations in the shape of the wings are not simply theoretical. By means of modifications in the wings of birds, I have been able to comprehend, in fact, that the wing shapes are due to the action of the surrounding medium or to the kind of motions, since the reactions occasioned by the motions of the wings result in tapering them in whole or in part.

The wings of birds present other peculiarities. They are all concave underneath in all directions. The longitudinal concavity, although quite decided, is never very great, since its radius is very long in all species. The transverse concavity, on the contrary, is very variable. On the under side, a wing shows, in front, a rather narrow resisting plane surface, averaging about a third of the width of the wing on birds with narrow wings and a fourth on birds with wide wings.

Then come the wing feathers, which are always curved downward and form a greater or smaller angle with the first plane, becoming more obtuse toward the body. For most birds, this angle is very large, as shown by No. 2 on Figure 61 and by the following table, the angle being measured at the middle of the forearm.

Series A	Degrees
Albatros (palmipedes, soarer)	120
Bar-tailed godwit (grallae, flapper)	138
Grebe (palmipedes, flapper)	129
Gannet (palmipedes, soarer)	122
Series B	
Heath-grouse (gallinae, flapper)	148
Crane (grallae, flapper-glider)	150
Pigeon (columbae, flapper)	155
Magpie (passeres, flapper)	155
Jackdaw (corvidae, flapper-glider)	156

Series B (Cont.)

Tawney owl (night raptores, flapper-glider)	158
Goatsucker (passeres, flapper-glider)	160
Hobby-hawk (day raptores, flapper-glider)	160
Buzzard (day raptores, soarer)	160

On the contrary, for the aquatic species living in strong currents of air, this angle is much smaller, always less than 140°. It is also smaller near the body. On large soarers, like the albatros and gannet, this angle is 120° at the elbow, which causes the wing in this vicinity to appear strongly arched downward (Fig. 6, No. 1) and presents, because of its narrowness, the form of a gutter, on which the action of the wind is very efficacious.

Bird wings vary, moreover, in thickness, according to the group and consequently the method of flight. In cross-section, a wing shows a sharp front edge, a concavity on the under side and a convexity on top which at first rises quite abruptly and then descends in an elongated arc, after making a larger or smaller angle. At this point there occurs the greatest thickness, which is greater at the elbow than at the wrist, as indicated by the following figures.

	Thickness of wing divided by cube root of weight.	
	At elbow	At wrist
Albatros (palmipedes, soarer)	0.35	0.30
Golden Eagle (day raptores, soarer)	0.28	0.25
Goshawk(day raptores, flapper-glider)	0.26	0.19
Pigeon (columbae, flapper)	0.26	0.17
Winter teal (palmipedes, flapper)	0.24	0.18
Curlew (grallae, flapper)	0.22	0.16
Litorn thrush (passeres, flapper)	0.21	0.14
Swift (passeres, flapper-glider)	0.16	0.13
Gray partridge (gallinae, flapper)	0.16	0.09
Humming bird (passeres, vibrater)	0.13	0.07

An examination of the above table shows that soarers have very thick wings, as compared with other birds, the albatros having the thickest. On the contrary, land flappers, like the gallinae and passeres, have the thinnest wings. The dimensions of bird tails are important. The tail is not always an organ of flight. For some species it serves chiefly as an ornament. On other species, like the wagtail, it serves for balancing when the

bird is moving on the ground. Usually, however, it serves chiefly as a rudder during flight. It also serves as a stabilizer during flight and as a brake in alighting. Its shape is generally that of the sector of a circle, whose center lies at the point of intersection of the tail feathers and whose circumference is more or less curved. Some species, however, have a bifurcated tail which is constantly in motion, due to the incessant turns made by these birds. These motions account for the shape of the tail of the kite, swift, tern, frigate-bird, etc., which fly with frequent and rapid evolutions.

I have been able to obtain useful information from the thorough study I have made of the dimensions of bird tails. I have weighed the tail feathers, measured the length and determined the area of each tail by spreading it out full width, taking care to leave the feathers overlapping as in nature. I have compared these data with the weight, length and area of the body in order to obtain comparable figures. I have also determined the ratio between the wing surface and the tail surface. Since I have only studied birds whose tails play no ornamental role, the ratios given in the following table retain all their interest from the viewpoint of flight.

	Relative length of tail	Relative weight of tail	Relative area of tail	Ratio of wing area to tail area
Series A.				
Raptores, day, flapper-gliders	2.4	10.3	6.3	2.8
Raptores, night, "	2.0	5.2	4.1	5.5
Columbae, flappers	1.9	8.5	4.2	3.1
Corvidae, flapper-gliders	2.6	7.3	6.1	3.1
Passeres, "	3.0	7.9	5.9	3.4
Passeres, flappers	2.2	6.5	3.9	3.7
Gallinae, "	1.2	2.4	1.9	4.9
Raptores, day, soarers	2.7	11.0	7.6	3.7
Gallinae, flappers	1.2	2.4	1.9	4.9
Series B.				
Palmipedes, soarers	1.7	4.3	2.5	7.4
Grallae, flappers	1.2	1.9	1.9	7.4
Palmipedes, swimmer-flappers	0.9	1.4	0.9	9.0
Palmipedes, diver-flappers	0.8	1.2	0.7	9.6
Grallae, flapper-gliders	1.3	1.9	2.0	12.6

From this table we see that there are two distinct series of birds:

1. Series A, composed of land species, for which the various tail ratios, although variable, are always quite large.

2. Series B, aquatic birds, accustomed to strong winds.

The groups are also classified in a similar manner for studying the acuity of the wings. These differences are clearly illustrated by the accompanying figure.

Consequently, a flying machine, constructed on the model of a soaring bird of prey, should, at certain moments of flight and especially in landing, have at its disposal a tail surface of 2.5 sq.m. for a wing surface of 10 sq.m. A machine designed for flight above water, after the manner of the soaring palmipedes, should, on the other hand, have a considerably smaller tail surface, about 1.4 sq.m. for a wing surface of 10 sq.m.

On the whole, the relative lengths, weights and areas are classified in a nearly identical manner. The soaring raptores, for example, which have the largest wing surface, have the greatest length, the greatest weight and the greatest relative tail surface.

The soaring palmipedes, however, have a heavier tail than is suitable, as they also have heavy and thick wings in proportion to the extent of their wing surface, by reason of their manner of flight. Their wings, in fact, need to offer a certain resistance to the winds they utilize for supporting themselves in the air. Moreover (and this comes to the support of my distinction between the factors causing the almost identical narrowness of the wings of certain flappers, like the hobby-hawks, swifts and humming-birds, and aquatic birds, like the soaring palmipedes) the tails are large and well developed on the former, but small on the latter. This goes to show that it is probably the action of the winds which has reduced the width of the wings and the length of the tails of these aquatic birds.

Lastly, we note that diving birds have very short tails, shorter than the tails of other birds frequenting the shores and marshes, but not leading an aquatic life. It is known that the posterior extremities of fishes are tapered. This tapering is the result of the eddying action of the water. I have shown that this shaping by water is exerted on diving birds in the same manner, tapering the posterior portion of their bodies and reducing the length and weight of their tail feathers, often to the point of almost complete annihilation, both in the palmipides and grallae and the diving passeres, such as the kingfishers, the relative length of whose tails is only 1.1, although the average among other passeres is 2.3.

On examining the muscles used by birds in flying, we find

the same general disposition, as in the muscles attached to the front limbs of other vertebrates. But certain of them, which play a very important role in the motion of the wings, appear to have undergone an abnormal development. These are the large pectoral, which gives the downward stroke of the wing, and the small pectoral, which serves to raise it.

Tatin raised the question as to whether the wing area per kilogram of bird, which is relatively small on large birds, does not necessitate excessive muscular work. He did not think so, since he believed that the weight of the muscles utilized in flight always bears a nearly constant ratio to the weight of the body, about a sixth on the average, with very few exceptions, the same as Legal and Reichel found. Moreover, the works of the latter led to the belief that the wings could be raised without any muscular effort. This is what Marey and Tatin called the passive lift of the wing, during which the downward-stroke muscles themselves worked, in order to soften the ascent which, without this moderating influence, would, they believed, sometimes be too sudden.

It seemed useful to me, however, to find whether the pectoral muscles, so well developed on birds, do not present differences in weight, according to the various methods of flight. I also endeavored to go into the problem in detail. The investigations I made on the weight of the pectorals led to conclusions differing from those of my predecessors, as shown by the following table.

	Mean wt of body grams	Relative wt. of large pectorals	Relative wt. of small pectorals	Relative wing area
Raptores, night, flapper-gliders	530.7	116.6	6.8	25.2
Palmipides, soarers	1608.4	123.5	10.9	21.3
Raptores, day, soarers	1402.7	135.3	7.3	26.7
Corvidae, flapper-gliders	325.6	135.3	10.5	19.0
Grallae, "	2614.1	152.0	14.4	23.8
Raptores, day, "	413.7	170.0	8.3	18.1
Passeres, flappers	34.7	175.0	17.1	14.3
" , flapper-gliders	35.0	177.5	14.9	19.0
Palmipedes, swimmer-flappers	966.6	185.0	20.9	8.5
Grallae, flappers	246.9	195.0	27.0	12.4
Gallinae "	699.0	195.5	61.6	8.1
Columbae "	326.3	233.6	39.5	11.9
Palmipedes, diver-flappers	836.8	135.0	21.2	6.4

We find that the relative weight of the small pectorals varies, on the whole, like that of the large pectorals and that, moreover, the same as there are groups more or less well equipped with wings, there are also groups more or less well provided with muscles, with this peculiarity, that the best rigged with wings have the poorest muscles. We learned in physiology that the work of which a muscle is capable is proportional to its weight. We find, in fact, that the strength of muscles is proportional to their size, i.e. to the number of fibers they contain.

The inverse ratio which exists, on the whole, between the weight of the pectoral muscles and the relative wing area is moreover very easily explained. Flappers (passeres, grallae, palmipedes, gallinae and columbae) have a rather small or very small wing area. They can support themselves in the air only by flapping their wings more or less rapidly. Their down-stroke muscles are well developed, by reason of the expenditure of the muscular energy required by this method of flight. The same holds true for the flapper-gliders. The size of the large pectorals is in proportion to the rapidity of the strokes. They are small on the night raptores, which flap slowly and glide frequently. They are very much enlarged on the passeres like the martins which fly by means of very rapid strokes separated by longer or shorter periods of gliding.

Soarers, on the contrary, flap only to ascend or support themselves, when there is no wind. Most of the time they soar by utilizing ascending or horizontal winds or glide through the air with their wings extended and without the least stroke. The muscular effort being small in all cases, the large pectorals are less powerful. As regards the small pectorals, the same reasoning applies to the soarers. On the latter, these muscles are small, because most of the time the wings are motionless and also because their lifting may be considered as automatic, on account of their large area. On birds with small wings, the weight of the small pectorals, on the contrary, is ten times as great as on soaring birds. Furthermore, although the up-stroke muscles of the latter average twenty times smaller than the down-stroke muscles, they are not over three times as small, for example, on the gallinae. Lifting the wing therefore requires a great muscular effort when the wings are small, this being true even for birds which fly scarcely at all, like the troglodytes or rarely like the diving palmipedes. Their down-stroke muscles are partially atrophied, but their up-stroke muscles are large enough to lift the wings during their rare flights.

In 1911 I explained the inverse ratio existing between the motive power of birds and the size of their wings. For birds, as well as for airplanes, small wings necessitate a large motive power, but with one point of difference. Hitherto the improve-

ments in engine construction have conduced to the idea that the best airplane is the one propelled by the most powerful engine and capable of carrying the heaviest load. On the contrary, soaring birds, which are the best fliers, have the smallest motive power and carry the smallest load.

The master section of a bird is shaped very much like that of a fish. There is, in both, an inversion of the body, i.e. a compression in front in the horizontal plane and a compression in the rear in the vertical plane. The master section of a bird, projected on the vertical plane or on the horizontal plane also has therefore the shape of a parabolic curve. If the bird is laid on its side, the summit of the curve is toward the head in the vicinity of the greatest width of the body which is always located at the posterior part of the shoulder joint and on the axis of the body, i.e. on the straight line between the beak and the tail. The horizontal plane, passing through this axis, divides the body into two very unequal parts. The ventral part is much the larger and the branch of the master section belonging to it is much the longer. When the bird is laid on its back, the summit of the curve is, on the contrary, situated on the ventral line toward the tail and both branches are equal.

The shape and, consequently, the position of this master section also vary with the manner of flight. Its projection on the horizontal plane is a parabolic curve whose branches are very divergent and whose summit is very much in front of the body proper on soarers and flapper-gliders. For flappers, this projection presents an elongated form. The branches, originating near the shoulder joints, extend backwards with the formation of an acute angle and join on the ventral line near the middle of the body, barely in front of the middle of the wings. The master section is therefore in front of the body in birds of small motive power and much farther back in those of great motive power (Fig. 8).

The general shape of a bird's body very evidently resembles the shape of a fish. Both the body and the wing are thicker in front and tapered toward the rear, this conformation being particularly noticeable in all raptores and passeres with their feathers on. It is less striking, though still evident, on other birds, because of the elongation of the neck. The ratio of the length of the neck to the cube root of the weight of the body varies in fact from 1.5 to 2.2 on land birds, while it exceeds 3 and even 4 on aquatic birds, so that the portion of the bird situated in front of the wings is at most equal to a quarter or a third of the total length of the bird on land species, but to a half and even more on aquatic and shore birds. The elongation observed on the latter, which is simply the consequence of an adaptation, not to a method of flight but to a particular kind of life, has resulted in modifying slightly the general shape of

the body, the larger end of which has become elongated and conical.

I have also determined the location of the center of gravity of my birds. For this purpose, I employed various methods, which I cannot describe here. I have found that the center of gravity, which is always situated practically in the vertical plane passing through the longitudinal axis, is consequently placed far forward on soarers and flapper-gliders and much farther back on flappers. In the former, it always corresponds to the front third of the wings and is nearer the front sixth in the best fliers. In flappers, on the contrary, it is nearly opposite the middle of the wings and approaches the line joining their middle points in proportion as they are poorer fliers (Figures 9 and 10). Moreover, the center of gravity always lies below the longitudinal axis and a little above the middle of the greatest thickness of the body in birds of small motive power and slightly below the middle in those with large motive power.

The length of this article and the data given on the characteristics of bird flight were necessary in order to render evident the inferences affecting aviation. Although it might have seemed important to endeavor to determine the dimensions of an airplane possessing the characteristics of a soaring, gliding or flapping bird, we did not have recourse, in 1913, for the construction of airplanes, to the data which could be furnished by the study of birds. The extensive comparisons I have made between the various groups have shown me that it would be possible to utilize for this purpose the figures given by nature, in spite of the great differences in weight between birds and airplanes. In the course of my researches on bird flight, I have found that the characteristics of birds vary according to whether they practice flapping, gliding or soaring flight. These characteristics are so similar for individuals with the same manner of flight, whatever may be their weight, that there is, so to speak, a constant for each dimension. It is therefore logical to suppose that, since a bird of 10 grams, belonging to a certain group, has relative dimensions very similar to those of another individual of the same group weighing 10000 grams, the same principle would hold true if there were birds weighing 100000, 500000 or 1000000 grams.

The method I have employed in studying birds has enabled me to obtain homogeneous ratios and to make useful comparisons. I have, in fact, compared the weight of the wings with the weight of the body, the length or width of the wings or tail with the cube root of the weight of the body, the area of the wings or tail with the cube root of the weight raised to the second power, according to the general formula $A/B = a$, in which A represents the dimension, the weight, or the area under consideration, B = the weight of the bird, its length furnished by the formula $\sqrt[3]{P}$, or its surface area obtained with the aid of the formula

$\sqrt[3]{P^2}$, P being expressed in grams, and lastly the desired ratio.

Under these conditions the determination of the characteristics of a monoplane becomes very easy. If it is to resemble a soaring raptor, for example, we know the ratio, namely, the mean ratio I have found for each of the relative dimensions of the raptor. B is also known, since it is the weight of the projected airplane in flying order. Consequently we may obtain A, i.e. the actual dimensions or areas, on multiplying B by a. I thus calculated, in 1913, the dimensions of an ideal monoplane, the weight of which in flying order would be 500 kg, a common weight at that time. I imparted these results to the academy of sciences. I showed that this method had the advantage of enabling, by starting from birds, the calculation of the exact dimensions of any airplane, according to the weight desired. I also indicated that, as regards all its characteristics, such a monoplane would not differ so much as one might think from monoplanes now in use. Anyway, my researches brought out the fact that an airplane thus constructed would be much shorter than the ones then in use.

After having counseled a shortening of the fuselage on the basis of the results of my researches, I had the satisfaction of seeing constructors make their airplanes shorter. The Ponnier monoplane, which participated in the Gordon-Bennett contest in 1913 and took second prize, was the first application, as well as the confirmation, of my data. Franz Reichel recounted the results in the Figaro of September 30, 1913, under conditions which I will quote here, because it proves that the study of birds may enable improvements in the design and construction of airplanes.

"New and marvelous exploits have been accomplished today. The contest was exciting, because there suddenly arose an unexpected rival from Prevost, Emile Védrines, who, this morning in an official trial of his Ponnier monoplane, made a speed of 202 kilometers per hour by flying over the 10 km course in 2' 58". The performance made a sensation. It disturbed the peace of the Deperdussin camp, to which its easy victory in the elimination contest had given a very natural confidence. The following are the conditions, under which the two airplanes, equally resplendent in their spruceness and the perfection of their lines (the Deperdussin all gilded, the Ponnier all white) presented themselves at the starting place. The Deperdussin had 9 sq.m. of wing surface and a 160 HP Gnome engine weighing 650 kg in flying order. The Ponnier had a wing area of 8 sq.m. and a 160 HP Gnome engine. Both were equipped with Chauviere propellers. The Ponnier possesses an interesting peculiarity. It has a length of only 5.5 meters and is the shortest of all. Its designer, Pagny, was led to give it this length as the result of the researches of Mr. Magnan who, after observing hundreds of birds and studying their dimensions, found that, in comparison, airplanes had fuse-

lages much too long in proportion to the width of the wings and demonstrated that, in passing from nature to the artificial, it would be best by the application of the former to the latter, to give the tail of an airplane a length not exceeding twice the width of the wings."

The objection might be made that such comparisons between birds and airplanes rest, among other things, on an extrapolation which is perhaps not justified, being based first on the ancient affirmation that birds above a certain size are incapable of flight. Some writers have, in fact, claimed that large birds are in a manifest condition of inferiority in comparison with others, as regards their aptitude for flight, by reason of the relative diminution of wing surface with increased weight of body, a law of which I have demonstrated the lack of accuracy in the proper sense of the word, since it is only the result of a mathematical artifice. The same writers, for the purpose of illustrating this hypothesis, mention the ostrich, which weighs up to 75 kg. Small species are known, however, which do not fly at all, like the apteryx, or which fly very little, like the troglodytes. The reason resides not in the question of weight, but in the adaptation to a particular kind of life, which has gradually eliminated the necessity of flight. Furthermore, there existed, in the cretaceous period, large pterodactyls and pteranodons, which lived in America and attained a wing span of 9 meters. Their conformation indicates that they flew after the manner of bats. I have measured the span and weight of bats and have divided the span by the cube root of the weight and found a mean ratio of 13.5. Under these conditions, by employing my formula $A/B = a$, the weight of the pteranodons should be about 287 kg. There have therefore existed fliers weighing nearly 300 kg. Perhaps there have also been birds even heavier and capable of flight, of which we do not know. The non-existence, at the present time, of such heavy fliers, does not therefore depend on the impossibility of flight of large animals, but on other causes. Hence I have the right to extrapolate. The comparison of a bird with an airplane would appear also as an error to other writers who, during the course of their investigations on birds, have not wished to take the time for lengthy observations, necessitating long trips, and are satisfied to talk of common species, pigeons and other flappers. Obviously, with such models, they can only reach unfavorable conclusions regarding the construction of flying machines in imitation of these birds. There can be, in fact, in the present state of our knowledge, no question of designing flying machines capable of producing wing strokes as powerful as those made by all the continuous flappers.

It is well to note that a monoplane with a powerful engine and a small wing area is the enlarged image of a grouse or partridge and moves through the air in a similar manner. Not only are the dimensions, given these airplanes by their builders, sim-

ilar to those I obtained in passing from the gallinae to airplanes as may be seen by an examination of Figure XII, but even the manner of flight does not differ so much as one might be led to believe. Grouse, partridge and racing monoplane, each have an enormous motive power, which control, it is true, different means of propulsion, but which produce identical results. In fact, such birds and airplanes advance in the same manner and also glide in the same manner between two spurts of the engine or at the instant of landing, due to the speed acquired.

I consider, however, that there are other types of birds which it is preferable to copy, because they support themselves in the air by means more within the power of man. These are the soarers, which flap their wings the least possible and in which the expenditure of motive force is always small, due to the utilization of the forces of nature placed at their disposal. By endowing a 750 kg airplane, for example, (Figure II) with the characteristics of a soaring raptor, we give it the qualities required for flight over land, for soaring on an ascending wind and for long glides. We are not extrapolating in an unjustifiable manner, for there is no reason to distinguish between a large monoplane and an eagle gliding through the air under the same conditions. If it is desired, on the contrary, to fly against strong winds, we must have aircraft designed for this purpose. We must then copy other types of birds accustomed to fly in the midst of squalls, which the raptores cannot do. We must pattern after the soaring sea birds.

All this goes to prove that comparisons between birds and airplanes cannot be made at random. It is a matter, above all, of making many observations in nature and subsequent logical applications, with a precision only obtained as the result of many observations, many measurements and much reflection.

All the considerations led me to think, in 1913, that aviation should be possible in another way than that of airplanes with powerful engines. I began by experimenting with a small airplane I had designed by copying the characteristics of certain birds like the soaring raptores. I tested the possibility of flying with such an airplane with the aid of a propeller driven by pedals and came to the conclusion that this manner of flight was impracticable, owing to the insufficiency of the power developed by the leg muscles. I decided that muscular force must be abandoned and that it would be better to take advantage of natural forces placed at our disposal, as well as at the disposal of birds. Whence the idea of soaring after the manner of sea birds. I then calculated the dimensions of an airplane possessing the characteristics of the latter and designed one for soaring in a horizontal wind. April 16, 1914, I exhibited this airplane to the "Congrès des Sociétés Savantes" and stated the conclusions I had drawn from my first experiments. I consider it interesting to re-

peat this communication, which was moreover published, in large part, in the "Journal Officiel" of April 17, 1914.

"A New Machine Enabling Man to Practice Soaring Flight."

"Soaring flight is a sort of continuous glide, executed by a bird without flapping his wings, in which he does not appear to utilize acquired speed and in the course of which he does not descend in the proper sense of the word. Sea birds, especially, practice this kind of flight almost exclusively. I have studied the evolutions of many soaring birds, particularly of the gannet, which usually describes circles or more or less perfect eights. They fly against the wind for awhile, during which they always ascend. Then, after turning, they let themselves glide through the air with the wind in their rear. They then repeat this program. These birds can soar, however, only when the wind is appreciable. When the wind is quite strong and continuous, but reinforced at intervals, the most perfect soaring flight can be observed.

"When a gust arrives, the strength of the wind increases up to a maximum, after which it decreases to a period of relative calm, which lasts till the succeeding gust. I have noticed that the soaring palmipides always present their beak to the wind when flying against the wind, as soon as a gust begins and as long as the force of the wind increases. During this period they are always ascending, but as soon as the force of the wind decreases, they turn their tails to the wind and glide through the air with an appreciable loss in altitude. There is in this connection an important inference, which I have drawn from my observations and experiments and which must be taken into account, in order to accomplish soaring flight.

"Many times man has attempted to imitate soaring birds. In my opinion, however, there is only one experimenter, Lilienthal, who can hold our attention. In spite of thousands of experiments, however, he could fly only very short distances by utilizing ascending air currents. I desired to attempt experiments of this kind anew. I considered that the ideal method would be, first of all, to design a flying machine on the exact lines of a soaring sea bird. In a recent communication to the Academy of Sciences on the characteristics of sea birds, I summarized the various numerical data pertaining to the soaring birds I have been able to study. I showed also that it is possible to apply the dimensions of birds to airplanes. By employing the formula which I then explained, I was able to calculate, for a given weight, the dimensions and surface areas of airplanes, which I considered as alone enabling flights against the wind. These data are contained in the following table.

Weight of airplane	kg.	80	90	100	lbs.	176.37	198.42	220.46
Wing area	sq.m.	3.52	3.79	4.07	sq.ft.	37.89	40.79	43.81
Weight of wings	kg.	15.56	17.50	19.45	lbs.	34.30	38.58	42.88
Span	m.	6.02	6.27	6.49	ft.	19.75	20.57	21.29
Chord of wing	m.	0.75	0.78	0.81	ft.	2.46	2.56	2.66
Length of tail	m.	0.77	0.80	0.83	ft.	2.53	2.62	2.72
Weight of tail	kg.	3.68	4.14	4.16	lbs.	8.11	9.13	9.17
Area of tail	sq.m.	0.42	0.46	0.49	sq.ft.	4.52	4.95	5.27
Length of airplane	m.	2.49	2.59	2.69	ft.	8.17	8.50	8.83

"These figures are susceptible of direct application, as regards such airplanes. The very short fuselage is perfectly feasible. I have already experimented with a light airplane, of the soaring sea bird type, weighing 80 kg, with very characteristic results. Such an airplane, launched on an inclined plane bent upward at its lower end, usually falls to the ground after a rather short bounce, if the launching against the wind is made without method and precision. On the contrary, it can be made to ascend, if the launching takes place at the moment when a gust begins and the force of the wind is increasing. But I soon found out that, while it is important to design a machine, it is also important to know how to manage it. It is necessary to learn how to fly such a machine, the same as to ride a bicycle or to swim. I actually constructed a soaring airplane weighing 150 kg, pilot included, on the plan of a sea bird of the albatros type. Like the latter, the airplane had very tapering wings, with a certain degree of elasticity at their trailing edges. The ratio of the span to the width of the wing was very great and the tail was considerably shortened. I also gave the wings great thickness and the shape of a gutter, the rear third being bent downward at an angle of about 60 degrees. Lastly, I provided the airplane with a spreading tail, so as to try to imitate the maneuvers of certain birds which, by giving contrary angles of incidence to their wings and tail, remain a long time in the air without making other motions and which can even, due to this disposition, remain stationary for a moment. I am publishing all these details with the hope of influencing a few true pilots to undertake, like myself, flights against the wind, while not concealing the difficulties they will encounter at first, before attaining complete success in soaring flight."

I was finally able to make several trials before the war with an airplane weighing 150 kg in flying order and represented in Figure 121. I succeeded once in raising myself directly from the ground, but under such adverse conditions that I capsized and smashed everything. This was the obligatory ending of my experiments, as I had no private funds for continuing them. The whole press then told the story of my experiments. Seven years later the Germans successfully took up soaring flight with flying machines, some of which were very similar to the one I exhibited to

the Congrès des Sociétés Savantes" in 1914. If I had had at my disposal the funds placed at the disposal of the Germans in 1920 and 1921, it would have been in France and not in Germany that the first soaring flights would have been made, if I can judge by the numerous proposals made to me then by pilots who recognized the importance of this manner of flight.

In any event, though my experiments did not enable me, for lack of funds, to accomplish real soaring flights and only proved to me the possibility of rising against the wind, they demonstrated to me the necessity of combining three conditions, in order to make soaring flights. It is necessary to have a wind interrupted by gusts and make use of them in the right way.. It is also necessary to have an airplane designed for such flights and with a shape as similar as possible to that of a soaring sea bird. Lastly, it is necessary to have a pilot who knows how to manage such an airplane. Those who would undertake soaring flights must satisfy themselves that neither of these conditions is lacking, if they are to be successful. If their airplanes do not possess the requisite qualities, they cannot soar. Unless the pilot endeavors to gain altitude by the method I have indicated, he cannot ascend and, if he is not a true pilot, he will immediately be arrested and will capsize, for here, still more than on an ordinary airplane, it is necessary to possess reflexes of the first order. In short, it is necessary to have both a good pilot and a good airplane, for the best pilot can do nothing with a fancifully designed airplane, nor a poor pilot do anything even with an ideal airplane.

To wish to imitate soaring sea birds and practice soaring flight is to seek to make progress in aviation and to enlist aeronautic science in the cause of the airplane without any engine or with an engine of small power and is, consequently, a means of obtaining quickly commercial communication at low cost, due to the utilization of aircraft which, as soon as they are in the air, can be piloted without expense for fuel with a speed approaching that of expresstrains. It also means an early knowledge of the aerodynamic conditions of flight, which the laboratory alone cannot give, and thus pave the way for great discoveries. It is also and especially the only way to render aviation accessible to everyone and to make it popular.

Translated by
National Advisory Committee
for Aeronautics

Fig. 1 - Relative Wing Surface According to the Manner of Flight.

1. Screech-owl (Tyto alba).- Raptores, night, flapper-glider. 2. Hawk (Circaëtus gallicus).- Raptores, day, soarer. 3. Crane (Megalornis grus).- Grallae, flapper-glider. 4. Gannet (Sula bassana).- Palmipides, soarer. 5. Jackdaw (Corvus monedula).- Corvidae, flapper-glider. 6. Dotterel (Charádrius morinellus).- Grallae, flapper. 7. Grosbeak (Cocothraustes vulgaris).- Passeres, flapper. 8. Cushat (Columba palumbus).- Columbae, flapper. 9. Heath-grouse (Tetrao tetrix).- Gallinae, flapper. 10. Garrot (Clangula clangula).- Palmipedes, swimmer-flapper. 11. Guillemot (Uria troille).- Palmipedes, diver-flapper. 12. Black martin (Apus apus).- Passeres, flapper-glider. 13. Peregrine falcon (Falco peregrinus).- Raptores, day, flapper-glider.

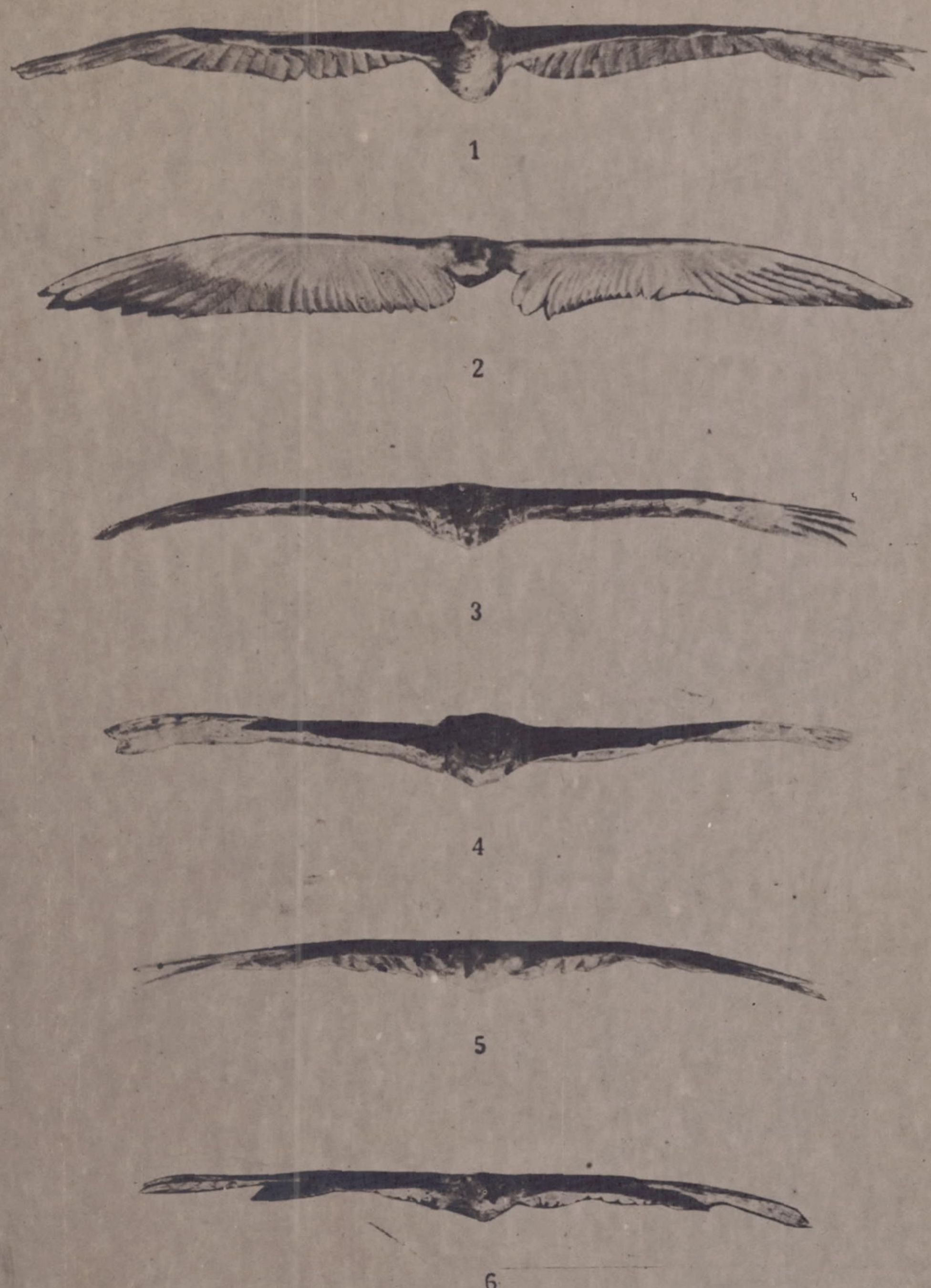


Fig. 2 - Relative Span according to the Manner of Flight. The various types are reduced to the size of a bird weighing one gram and then further reduced one-fifth.

1. Heron (Ardea cinerea).- Grallae, flapper-glider. 2. Black-headed gull(Larus ridibundus).- Palmipedes, soarer. 3. Buzzard (Buteo vulgaris).- Raptores, day, soarer. 4. Eagle-owl (Bubo bubo).- Raptores, night, flapper-glider. 5. Rook.(Trypanocorax frugilepus).- Corvidae, flapper-glider. 6. Goshawk (Accipiter gentilis).- Raptores, day, flapper-glider.

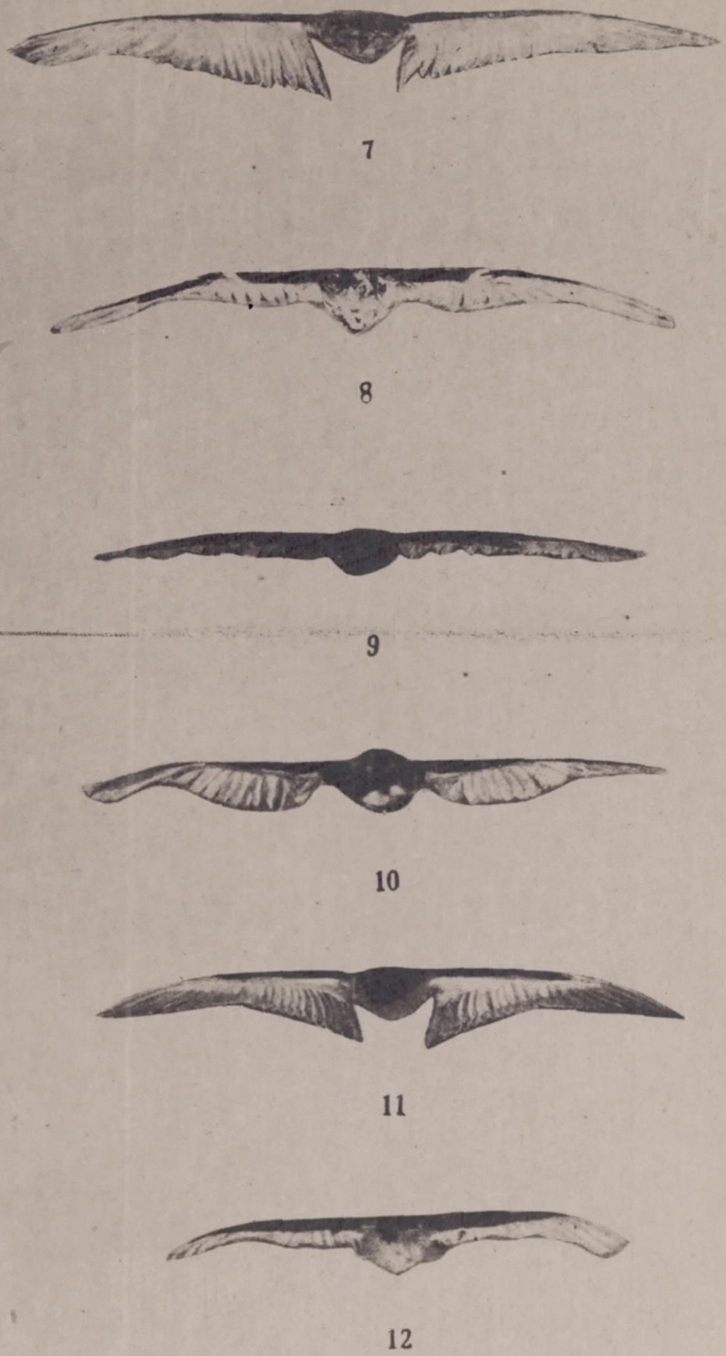


Fig. 3 - Relative Span according to the Manner of Flight. The various types are reduced to the size of a bird weighing one gram and then further reduced one-fifth.

7. Golden plover (Charadrius apricarius).- Grallae, flapper. 8. Cushat (Colomba paluubas).- Columbâs, flapper. 9 Yellowhammer (Emberiza citrinella)- Passeres, flapper. 10. Kingfisher (Alcedo ispida).- Passeres, diver. 11. Wild duck (Anas platyrhyncus).- Palmipedes, swimmer-flapper. 12. Gray partridge (Perdix perdix).- Gallinae, flapper.

Fig. 4 - Morphology of Wings according to Manner of Flight.

1. Golden eagle (Aquila chrysaetus). 2. Hawk (Circaetus gallicus). 3. Buzzard (Buteo vulgaris). 4. Fulvous vulture (Gyps fulvus). 5. Royal kite (Milvus milvus). 6. Lammergeier (Gypaetus barbatus grandis): Raptores, day, soarers. 7. Screech-owl (Tyto alba). 8. Eagle-owl (Bubo bubo). 9. Barn-owl (Strix aluco): Raptores, night, flapper-gliders. 10. Crane (Megalornis grus). 11. Night heron (Ardea nycticorax). 12. Spoonbill (Platalea leucorodia): Grallae, flapper-gliders. 13. Tichodrome (Tichodroma murarla). 14. Hoopoe (Upupa epops). 15. Troglodyte (Troglodytes vulgaris): Passeres, flappers. 16. Jackdaw (Corvus monedula): Corvides, flapper-glider. 17. Red-backed shrike (Lanius senator). 18. Golden oriole (Oriolus galbula). 19. Wryneck (Iynx torquilla). 20. Goldfinch (Carduelis elegans). 21. Sedge warbler (Acrocephalus phragmitis): Passeres, flappers. 22. Cushat (Columba palumbus). 23. Turtle dove (Turtur turtur): Columbae, flappers.

Fig. 5 - Morphology of Wings according to Manner of Flight.

1. Heath-grouse (Tetrao tetrix). 2. Red grouse (Lagopus scoticus). 3. European Ptarmigan (Lagopus mutus). 4. Quail (Coturnix coturnix): Gallinae, flappers. 5. Peregrine falcon (Falco peregrinus). 6. Hobby-hawk (Falco subbuteo): Raptores, day, flapper-gliders. 7. Humming-bird (Eupherusa eximia): Passeres, vibrater. 8. Black martin (Apus apus). 9. Goatsucker (Caprimulgus europaeus). 10. House martin (Hirundo urbica): Passeres, flapper-gliders. 11. Gannet (Sula bassana). 12. Albatros (Diomedia exulans). 13. Gray puffin (Puffinus kuhli). 14. Great black-backed gull (Larus marinus). 15. Frigate-bird (Tachypetes aquilus). 16. Storm-petrel (Procellaria pelagica): Palmipides, soarers. 17. Great ringed plover (Charadrius hiaticula). 18. Dotterel (Charadrius morinellus). 19. Curlew (Numenius arquatus). 20. Lapwing (Vanellus vanellus): Grallae, flappers. 21. Wild goose (Anser fabalis). 22. Brant (Branta bernicla). 23. Garrot (Clangula clangula). 24. Morillon (Nyroca fuligula): Palmipedes, swimmer-flappers. 25. Merganser (Mergus albellus). 26. Tufted grebe (Colymbus cristatus). 27. Penguin (Alca torda). 28. Guillemot (Uria troille): Palmipedes, diver-flappers

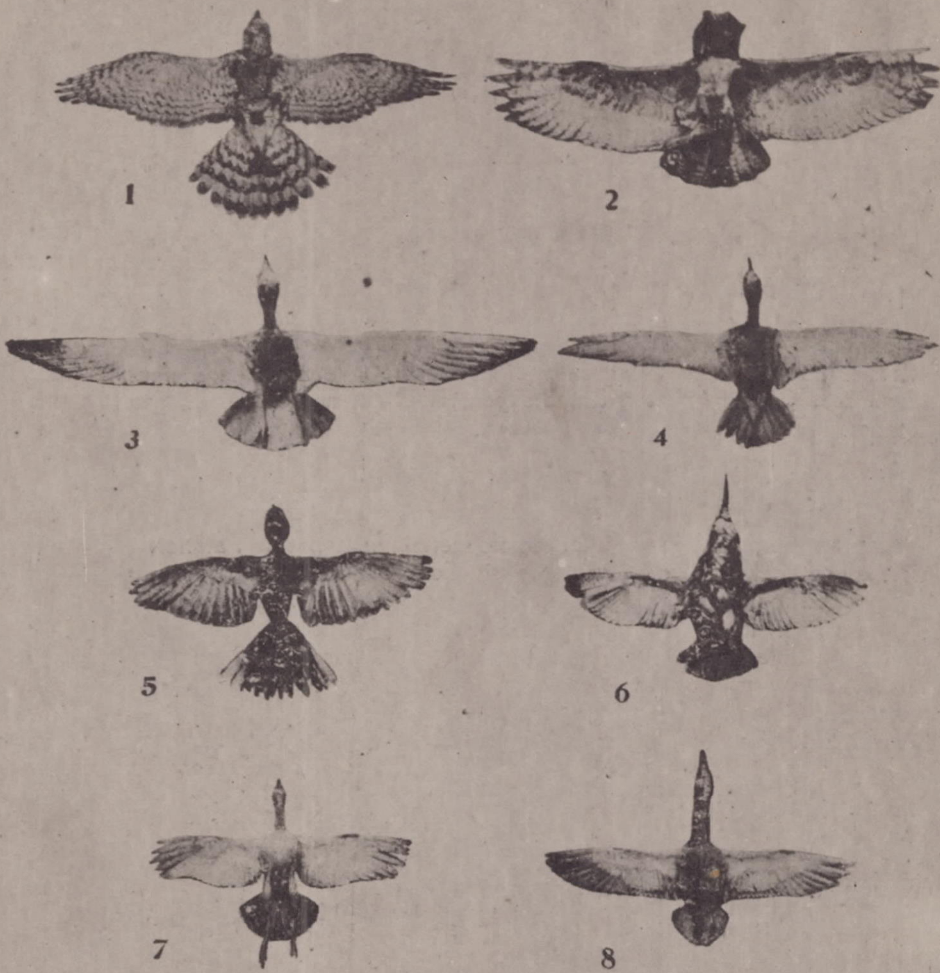


Fig. 6 - Relative Area of Tail according to Manner of Flight. The various types are reduced to the dimensions they would have, if each bird weighed one gram.

1. Goshawk (Accipiter gentilis): Raptores, day, flapper-glider. 2. Eagle-owl (Bubo bubo): Raptores, night, flapper-glider. 3. Black-headed gull (Larus ridibundus): Palmipedes, soarer. 4. Golden plover (Charadrius apricarius): Grallae, flapper. 5. Yellowhammer (Emberiza citrinella): Passeres, flapper. 6. Kingfisher (Alcedo ispida): Passeres, diver-flapper. 7. Gray partridge (Perdix perdix): Gallinae, flapper. 8. Wild duck (Anas platyrhyncus): Palmipedes, diver-flapper.

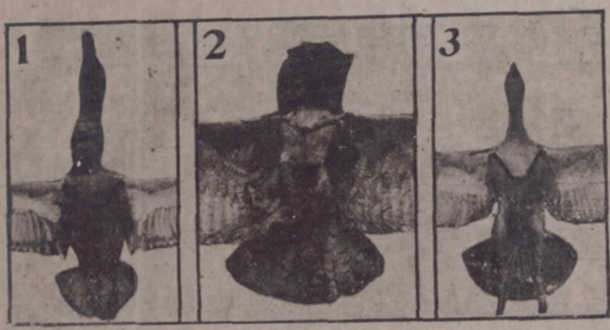


Fig. 8 - Shape and Location of the Master Section.

1. Wild duck (Anas platyrhyncus): Palmipedes, swimmer-flapper. 2. Eagle-owl (Bubo bubo): Raptores, night, flapper-glider. 3. Gray partridge(Perdix perdix): Gallinae, flapper.

Fig. 9 - Position of Center of Gravity, as Seen from Below.

1. Saint Martin's buzzard (Circus cyaneus): Raptores, day, soarer. 2. Black martin (Apus apus): Passeres, flapper-glider. 3. Capercaille (Tetrao urogallus): Gallinae, flapper. 4. Curlew (Numenius arquatus): Grallae, flapper.

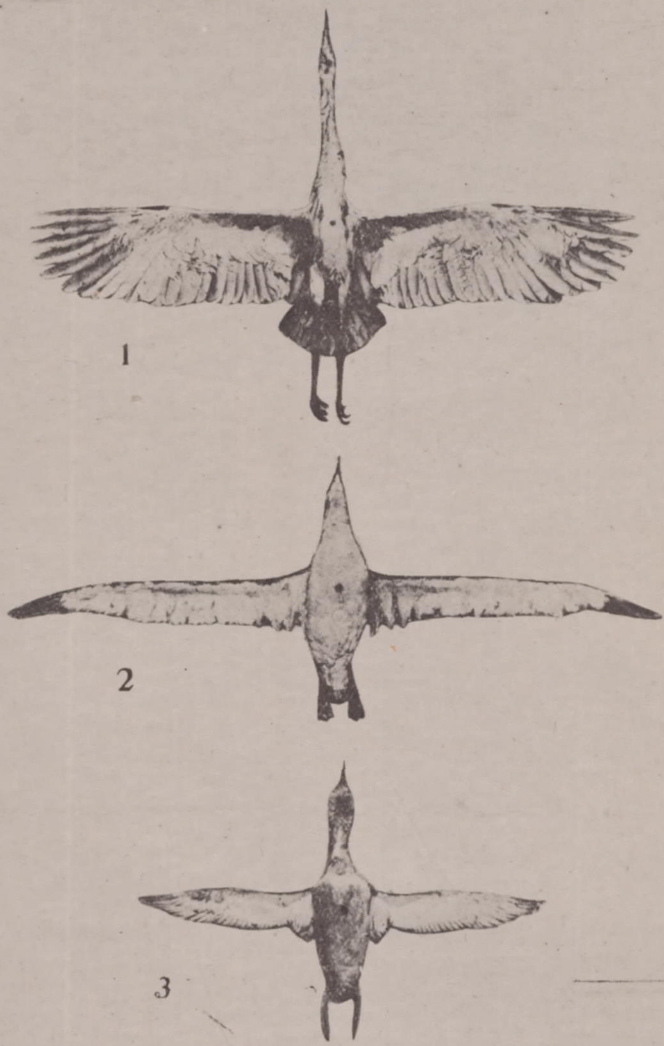


Fig. 10 - Position of Center of Gravity, as Seen from Below.

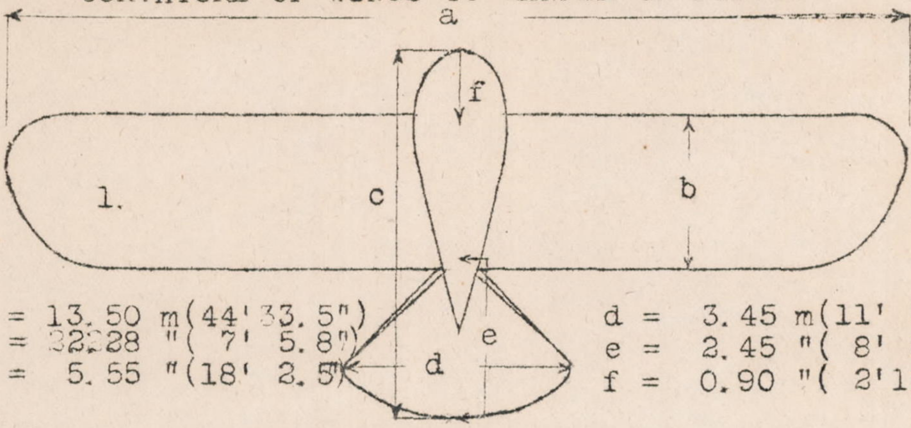
1. Heron (Ardea cinerea): Grallae, flapper-glider. 2. Albatros (Diomedea exulans): Palmipedes, soarer. 3. Black-throated loon (Gavia arctica): Palmipedes, diver-flapper.

The relative sizes of the birds are retained.

Series B Series A

1. Albatros-Palmipedes, soarer. 2. Buzzard-Raptores, day soarer.

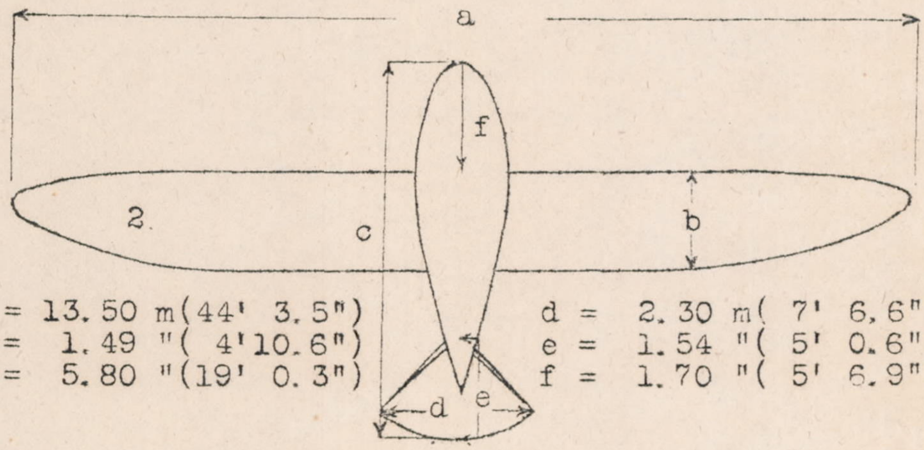
Fig. 7. CURVATURE OF WINGS TO MANNER OF FLIGHT.



a = 13.50 m(44' 3.5")
b = 2.28 "(7' 5.8")
c = 5.55 "(18' 2.5")

d = 3.45 m(11' 3.8")
e = 2.45 "(8' 0.5")
f = 0.90 "(2'11.4")

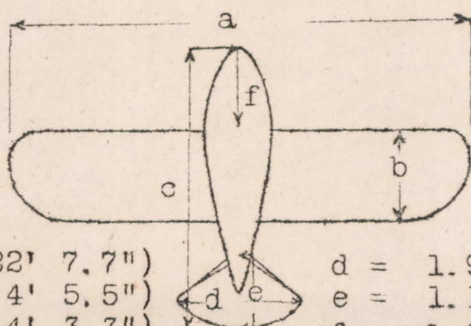
1. A day soaring raptor.



a = 13.50 m(44' 3.5")
b = 1.49 "(4'10.6")
c = 5.80 "(19' 0.3")

d = 2.30 m(7' 6.6")
e = 1.54 "(5' 0.6")
f = 1.70 "(5' 6.9")

2. A soaring palmiped.



a = 6.90 m(22' 7.7")
b = 1.36 "(4' 5.5")
c = 4.35 "(14' 3.3")

d = 1.90 m(6' 2.8")
e = 1.10 "(3' 7.3")
f = 1.20 "(3'11.2")

3. A flapping gallina.

Fig. 11. SHAPE AND DIMENSIONS OF A MONOPLANE WEIGHING (1653.5 lb.
750 KG. IN FLYING ORDER AND COPYING AS ABOVE.

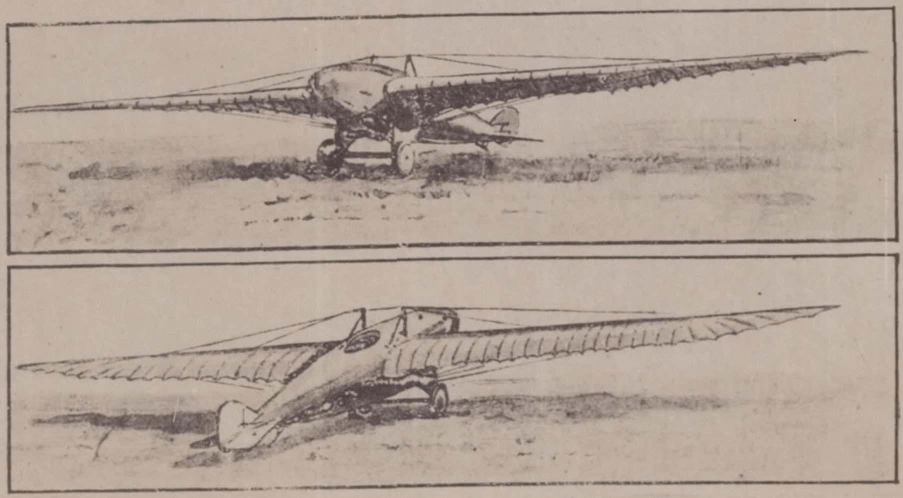


Fig. 12 - Airplane Designed by the Writer in 1914 for Soaring Flight in a Horizontal Wind.